CBC A LEVEL BIOLOGY DISCUSSION ITEMS by

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Item 1: Anaerobic Respiration & Bio-Ethanol Production

A youth development group in Jinja established a small-scale commercial distillery to produce bio-ethanol from sugarcane molasses using a local strain of yeast (Saccharomyces cerevisiae). During the initial setup, the team used two different types of fermentation vats: Vat A was left open to the atmosphere for the first 48 hours before being sealed, while Vat B was sealed completely airtight from the very beginning. Both vats started with an identical glucose concentration of 150g/l and equal yeast starter cultures.

At the end of the 48-hour incubation period, raw data on various growth and metabolic parameters was collected and recorded in the table below:

Metabolic Parameter Monitored (at 48 Hours)	Vat A	Vat B (Strictly Sealed)
Yeast Cell Population Density ($X10^6$ cells m/L)	124.5	16.2
Residual Glucose Concentration (g/l)	45.0	12.0
Ethanol Concentration Achieved (%v/v)	2.1	9.8
Total Carbon Dioxide (CO2) Evolved (Litres)	38.0	14.5

Tasks

a) Account for the biological phenomenon that explains the drastic differences in yeast population density and final ethanol concentration between Vat A and Vat B.

b) Describe the molecular pathway through which the residual glucose is processed in Vat B to yield ethanol, highlighting the significance of this specific pathway to the continued survival of the yeast cells.

c) The group wants to maximize their ethanol output while minimizing the cost of raw sugar. Formulate an operational strategy for managing oxygen levels in the vats based on the raw data provided.

Item 2: Oxidative Phosphorylation & Environmental Pharmacology

During a prolonged dry spell in Amuria District, some families resorted to consuming wild, bitter cassava varieties without subjecting them to traditional processing methods (soaking and sun-drying). Several family members were rushed to a local health center presenting with acute cellular hypoxia, rapid breathing (hyperventilation), dizziness, and muscle fatigue.

Clinical lab reports revealed that the patients had high blood oxygen saturation levels, yet their cellular ATP levels were dangerously low. Toxicologists confirmed the presence of cyanide ions in the blood. Cyanide is a potent metabolic poison that binds irreversibly to Cytochrome c Oxidase of the Electron Transport Chain in the inner mitochondrial membrane.

Tasks

a) Explain the precise molecular consequence of cyanide binding to Cytochrome c Oxidase on the generation of the proton gradient across the inner mitochondrial membrane.

b) Analyze the paradox presented in the medical report: Why did the patients exhibit high blood oxygen saturation levels while simultaneously suffering from severe cellular energy failure?

c) A medical intern suggested administering an alternative electron acceptor or a drug that creates artificial leaks in the inner mitochondrial membrane (like DNP) to treat the patients. Evaluate the scientific validity of using a membrane-leaking drug to restore ATP synthesis in this scenario.

Item 3: High-Altitude Physiology & The Lactate Threshold

Uganda's elite long-distance runners train in Kapchorwa, a high-altitude region located approximately 2,500 meters above sea level. Biologists from the Uganda Olympic Committee carried out a sports science study comparing a group of trained athletes from Kapchorwa against a control group of healthy but untrained university students from Kampala (low altitude).

Both groups underwent an incremental treadmill test where running intensity was progressively increased every 3 minutes. The researchers monitored the subjects' blood lactate accumulation against their total working capacity of O2. The baseline resting blood lactate level for both groups was 1.0mmol/l. The raw experimental data is compiled below:

Exercise Intensity (% of VO_2)	Blood Lactate of Kampala Students (mmol/l)	Blood Lactate of Kapchorwa Athletes (mmol/l)
20	1.2	1.1
40	1.5	1.2
50	2.4	1.3
60	4.8	1.5
70	8.2	1.9
80	11.5	2.8
90	Exhaustion /stopped	5.4
100	Exhaustion /stopped	9.9

Tasks

a) Identify the specific exercise intensity thresholds where rapid blood lactate accumulation begins for both groups, and account for the molecular shift in metabolism that causes this accumulation in the Kampala students.

b) Analyze two cellular or enzymatic adaptations that the Kapchorwa athletes possess that allow them to delay the accumulation of lactate at higher workloads compared to the Kampala students.

c) If an athlete runs a 10,000-meter race completely at an intensity level above their lactate threshold, predict and justify the physiological impact this will have on their skeletal muscle performance towards the final laps of the race.

Item 4: Autosomal Linkage and Crossing Over in Cowpeas

The National Agricultural Research Organisation (NARO) at the Serere Gold Crop Research Institute is breeding cowpeas (Vigna unguiculata) to improve market traits. Plant geneticists crossed a true-breeding variety featuring Smooth, Black seeds with another true-breeding variety featuring Wrinkled, Brown seeds.

All the resulting F1 generation plants produced Smooth, Black seeds. An F1 plant was then backcrossed (test-crossed) with a double antisense Wrinkled, Brown seeded parent plant. The raw phenotypic data from 1,200 offspring of this test cross is compiled in the table below:

Offspring Phenotype	Number of Individual Plants
Smooth, Black seeds	524
Wrinkled, Brown seeds	516
Smooth, Brown seeds	82
Wrinkled, Black seeds	78

Tasks

a) Deduce the dominant phenotypes and state whether the genes controlling seed texture and seed color undergo independent assortment or autosomal linkage. Justify your answer using the data.

b) Calculate the crossover value (recombination frequency) between the two gene loci, and explain what this distance implies about their physical location on the chromosome.

c) Describe the physical mechanism occurring during prophase I of meiosis that accounts for the emergence of the Smooth-Brown and Wrinkled-Black phenotypes.

Item 5: Pedigree Tracking of X-Linked Conditions via Family Data

A family from Kanungu District visited the genetics counseling unit at Mulago National Referral Hospital due to the recurring incidence of a severe muscular weakening condition known as Duchenne Muscular Dystrophy (DMD).

Because drawing a standard pedigree chart on-site was delayed, the clinical geneticist recorded the direct family clinical histories across three generations into a structured lineage table. The raw distribution of the disease status within the family is detailed below:

Generation Individual Identifier Biological Sex Parentage Clinical Health Status

Gen I 1 (Grandfather) Male Unknown Normal vision & muscle tracking

2 (Grandmother) Female Unknown Normal vision & muscle tracking

Gen II 3 (Uncle) Male Offspring of 1 & 2 Affected by DMD

4 (Aunt) Female Offspring of 1 & 2 Normal vision & muscle tracking

5 (Mother) Female Offspring of 1 & 2 Normal vision & muscle tracking

6 (Father) Male Married into family Normal vision & muscle tracking

Gen III 7 (Son 1) Male Offspring of 5 & 6 Affected by DMD

8 (Daughter 1) Female Offspring of 5 & 6 Normal vision & muscle tracking

9 (Son 2) Male Offspring of 5 & 6 Normal vision & muscle tracking

Tasks

a) Determine the precise mode of inheritance of Duchenne Muscular Dystrophy based on its distribution pattern across the generations. Provide two reasons to support your conclusion.

b) Using the genetic symbols X^D for the normal allele and X^d for the muscular dystrophy allele, state the definite genotypes of individuals 2, 5, and 7.

c) If individuals 5 and 6 intend to have a fourth child, calculate the mathematical probability that their next child will be a male who is affected by the condition. Show your working using a genetic cross.

Item 6: Non-Mendelian Epistatic Interactions in Sorghum

Sorghum (Sorghum bicolor) is an essential climate-resilient food crop managed by the National Semi-Arid Resources Research Institute (NaSARRI) in Serere. The grain pericarp color is determined by two independently assorting genes, Gene Y and Gene I.

Botanists crossed a true-breeding variety producing Purple grains with a true-breeding variety producing White grains. The entire F1 generation produced Purple grains. When the F1 plants were self-pollinated, the F2 generation yielded a mixture of seed colors. The raw numeric counts of the grains harvested from the F2 population are presented below:

Grain Color Phenotype Number of Seeds Counted

Purple Grains 562

Red Grains 188

White Grains 250

Tasks

a) Convert the raw data counts into the simplest whole-number mathematical ratio. From this ratio, identify the specific type of non-Mendelian gene interaction governing sorghum grain color.

b) Propose a biochemical pathway hypothesis that explains how the interaction between Gene Y and Gene I produces the white phenotype even when one of the structural dominant alleles might be present.

c) If an F1 plant (heterozygous at both loci) is cross-pollinated with a completely homozygous recessive white-grained plant, predict the phenotypic ratio of the resulting progeny.

Item 7: Capture-Mark-Recapture Method and Aquatic Pollution

The National Fisheries Resources Research Institute (NaFIRRI) conducted an ecological audit on the population status of Nile Tilapia (Oreochromis niloticus) in a semi-enclosed bay on Lake Victoria near the Kampala industrial zone. The study aimed to evaluate the impact of effluent discharge from neighboring factories on fish populations over a four-year period (2022 to 2026).

Ecologists utilized the Capture-Mark-Recapture (Lincoln Index) technique. In both study years, a team deployed standardized gill nets to capture the first sample, marked the fish safely with non-toxic subcutaneous fluorescent tags, and released them back into the bay. Two weeks later, a second sample was collected using identical trapping efforts. The raw ecological field data is compiled below:

Ecological Field Parameters	Year 2022 (Baseline)	Year 2026 (Post-Industrial Expansion)
Number of fish caught and	450	320

marked in 1st sample (N1)		
Total number of fish caught in 2nd sample (N2)	480	350
Total number of fish caught in 2nd sample (N2)	90	140
Dissolved Oxygen (DO) levels in the bay (mg/l)	6.8	3.2

a) Calculate the estimated total population size of Nile tilapia in the bay for both the year 2022 and the year 2026 using the Lincoln index.

b) Account for the significant shift in the fish population dynamic between 2022 and 2026 by linking physical water parameters

c) Critically evaluate two core ecological assumptions of the Capture-Mark-Recapture method that might be violated in the 2026 study due to the toxic effects of industrial water pollution.

Item 8

Over the last decade, parts of the Mabira Forest ecosystem have experienced heavy degradation due to illegal logging, which opened up the dense canopy. A local environmental NGO has been monitoring a 5-square-kilometer block of the forest. Their data shows that following the canopy opening, an invasive, fast-growing heliophyte (sun-loving plant) rapidly colonized the forest floor, completely outcompeting native undergrowth tree seedlings.

The NGO tracked the energy transfer across three trophic levels: the invasive plant, a dominant herbivorous caterpillar population that feeds exclusively on it, and a local species of insectivorous songbird. Surprisingly, despite a massive explosion in the biomass of the invasive plant, the songbird population has plummeted by 40%. Ecological physiological tests revealed that the caterpillar has evolved a metabolic mechanism to sequester a mild toxin produced by the invasive plant, making the caterpillars highly unpalatable and slightly toxic to the birds.

Tasks

a) Act as the Lead Conservation Officer for the National Environment Management Authority (NEMA). Write a technical brief to the field team addressing the following:

b) Construct an annotated flow diagram showing the transfer of energy through this specific degraded forest food chain. Use the 10% Rule of thermodynamic transfer to explain why energy limits the system to a finite number of trophic levels, regardless of plant biomass explosions.

c) Analyze the ecological and evolutionary factors that led to the collapse of the songbird population despite the abundance of caterpillars, specifically referencing the concepts of carrying capacity and niche differentiation.

d) Propose two ecologically sound, non-chemical interventions to restore the natural food web dynamics and protect native tree seedlings in this section of Mabira Forest.

Item 9: Population Ecology & Human-Wildlife Conflict

Communities living adjacent to Queen Elizabeth National Park have reported an unprecedented surge in conflicts with African elephant populations. Due to prolonged dry spells in the region, the primary water holes inside the park have dried up, forcing elephant herds to migrate outward into communal lands. The elephants frequently raid local maize and banana plantations, which are heavily treated with synthetic phosphate fertilizers.

A team of zoologists sampled the elephant dung and water sources along the park boundaries. They discovered that the migrating elephants are experiencing a high incidence of a gastrointestinal parasitic infection. Interestingly, population modeling data indicates that while the overall birth rate of the elephants has remained stable, the mortality rate among calves under three years old has doubled since the boundary raids began.

Tasks

You have been invited by the Uganda Wildlife Authority (UWA) to present a research paper at a community-inclusive conservation symposium. In your paper:

a) Explain how the abiotic changes within the park acted as an environmental pressure that altered the spatial distribution and density-dependent factors of the elephant population.

b) Deduce the biological correlation between the elephants' consumption of fertilizer-laden crops and their increased susceptibility to gastrointestinal parasites, linking this to animal homeostatic immunity.

c) Evaluate the long-term impact of the increased calf mortality rate on the population structure (age pyramids) and genetic diversity of this elephant herd over the next three decades.

Item 10: Biogeochemical Cycling & Aquatic Pollution

In the Murchison Bay area of Lake Victoria near Kampala, local fishermen have reported a massive die-off of Nile Tilapia. Environmental scientists observed that the water has turned a thick, opaque green color, with a foul odor. Upstream from the bay, several unregulated urban settlements and a commercial laundry factory discharge raw sewage and detergent effluents directly into the primary wetland channel that feeds into the lake.

Measurements of water quality parameters over a two-week period yielded the following data trends:

Tasks

As an aquatic ecologist compiling a report for the Ministry of Water and Environment, use the provided data to address the following:

Graphically represent or schematically map out the biochemical chain of events (Eutrophication) that connects the high phosphate levels upstream to the critical dissolved oxygen drop in the Lake Bay.

Parameter	Upstream /wetland entry	Midstream/channel	Lake bay/die off site
Phosphate concentration	Low 0.02mg/l	High 1.8mg/l	Very high 3.5mg/l
Dissolved oxygen	High 7.2 mg/l	Moderate 4.5mg/l	Critical 1.1mg/l
Biochemical oxygen demand	Low 2.0mg/l	High 12.5mg/l	Extremely high 28.0mg/l

a) Explain the physiological mechanism that caused the death of the Nile Tilapia, contrasting their respiratory requirements with the metabolic activities of the decomposers (saprotrophs) active in the bay.

b) The surrounding wetlands are dominated by papyrus reeds (Cyperus\ papyrus). Explain the ecological role of this wetland vegetation in nutrient cycling, and justify why restoring the degraded wetland buffer is a more sustainable solution than chemically treating the lake water.

Item 11: Ecological Succession & Sustainable Land Management

In the hilly terrains of Kabale district, a massive landslide completely cleared a steep hillside slope, removing all vegetation, organic topsoil, and leaving behind bare volcanic rock. Two years after the disaster, a biology field study group visited the site and observed that the bare rock surfaces were patches of crusty lichens and small mosses.

Five kilometers away, another hillside that had been cleared by fire for agriculture five years ago but subsequently abandoned was covered in dense elephant grass, ferns, and small woody shrubs. Local farmers want to utilize both sites for intensive potato farming immediately to boost their household incomes.

Tasks

As the District Agricultural Extension Officer, write an advisory guide for the local farming cooperative. Your guide must cover the following:

a) Compare the biological processes occurring at the landslide site (Primary Succession) with those at the fire-cleared site (Secondary Succession), explicitly stating why the rate of community transformation differs between the two.

b) Explain the vital role of the lichens and mosses (pioneer species) at the landslide site in transforming the abiotic environment to pave the way for future trophic levels.

c) Formulate a scientifically backed recommendation to the farmers regarding which site is immediately viable for agriculture, and outline the ecological consequences to the local watershed if they carry out intensive tillage on the landslide hillside prematurely.

Item 12

A dairy farming cooperative in Mukono district is struggling with a high incidence of a metabolic disorder in their high-yielding exotic breeds. A local veterinary officer suggests treating the cattle with an oral formulation containing localized enzymatic complexes and an intermediate compound of the Krebs cycle. The cooperative wants to understand how this oral solution chemically resolves the lethargy and low milk production in their cattle. Meanwhile, a student from a nearby university suggests that instead of lifelong supplementation, the

cooperative should look into genetic modification targeting glucose transporter proteins (GLUT) in the bovine mammary glands to sustainably boost energy extraction.

Tasks

As a biology consultant, write an advisory brief to the dairy farming cooperative. In your brief:

a) Explain how the tissue-level organization and surface area dynamics of the bovine digestive tract (specifically the small intestines) influence the absorption of the oral solution.

b) Analyze how a named intermediate compound of the Krebs cycle bypasses early metabolic bottlenecks to enhance ATP production within the cellular mitochondria of the cattle.

c) Critically evaluate the ethical implications and biological feasibility of using genetic engineering to modify bovine glucose transporters (GLUT) to maximize energy production versus using long-term chemical supplementation.

Item 13

Due to changing weather patterns in the cattle corridor of Uganda (e.g., Nakasongola district), prolonged droughts and soaring temperatures are threatening food security. Farmers are debating whether to completely abandon native C3 legumes in favor of drought-resistant C4 cereal crops like specific varieties of sorghum. Agricultural researchers at NaSARRI in Serere have noticed that while C4 crops maintain a high photosynthetic rate during hot days, their growth slows down significantly when the region experiences unexpected prolonged cool, cloudy overcast weeks.

Tasks

a) Design a sensitization poster or guide for the Nakasongola District Agricultural Extension Officer to educate local farmers. Your guide must address the following:

b) Compare the structural anatomy vs. typical mesophyll arrangement) and biochemical pathways of C3 and C4 plants to explain why sorghum outperforms native legumes under high temperatures and scarce water.

c) Formulate a scientific explanation for why the C4 sorghum varieties underperform during unusual cool, overcast weeks, referencing enzyme kinetics and the energy cost of their specific photosynthetic pathway.

d) Suggest practical, sustainable agricultural management strategies (such as leveraging plant growth regulators or intercropping) that farmers can use to mitigate the effects of fluctuating photoperiods and water stress.

Item 14

Encroachment and deforestation around the Budongo Forest Reserve have fragmented the habitat into isolated forest patches surrounded by large sugarcane plantations. A local conservation group monitoring native rodent populations discovered that a particular species of forest mouse has split into two isolated populations. Population A lives deep within the remaining forest, while Population B lives in the fragmented forest edges bordering the sugarcane plantations.

Farmers in the sugarcane plantations have been heavy users of Pesticide X to control agricultural pests. Recent data shows that the sugarcane pests have rapidly developed resistance to Pesticide X. Concurrently, genetic screening of the mice in Population B (near the plantations) reveals a sudden reduction in genetic diversity and a high frequency of a unique, non-Mendelian trait that is completely absent in the deep-forest Population A.

Tasks

Develop an environmental impact assessment report for the National Environment Management Authority (NEMA). Your report must include:

a) An explanation of how the rapid development of resistance to Pesticide X in sugarcane pests occurs through natural selection, and a proposed Integrated Pest Management (IPM) strategy to mitigate the issue.

b) An analysis of the evolutionary mechanisms responsible for the divergence, reduction in genetic diversity, and appearance of the unique trait in mouse Population B compared to Population A.

c) A predictive evaluation of the long-term ecological risks to the Budongo Forest ecosystem if these fragmented mouse populations face complete reproductive isolation or eventual extinction, and outline actionable strategies to maintain ecological balance.

Item 15 Sympatric Speciation & Ecological Niche Divergence

Lake Nabugabo, a small satellite lake separated from Lake Victoria thousands of years ago, contains several closely related species of cichlid fish. A team of researchers from Makerere University discovered that two distinct species of these cichlids occupy the exact same rocky shoreline patch.

Species X has a blunt snout, dull blue coloration, feeds primarily on algae encrusted on the rocks, and breeds exclusively during the daytime peak when sunlight maximizes the visibility of its blue mating territory.

Species Y has an elongated snout, bright yellow-and-orange striped coloration, feeds on small macroinvertebrates hiding in the deep rock crevices, and carries out its elaborate courtship dance only at dusk.

Industrial runoff from nearby commercial farms has recently increased water turbidity (cloudiness) in this specific bay. A ten-year monitoring study reveals that since the water became cloudy, the physical boundaries between the territories of Species X and Y have broken down, and fishermen are increasingly catching strange-looking cichlids that display a blend of both blue and orange-striped coloration. Genetic tests confirm these are fertile hybrids, and the distinct populations of Species X and Species Y are actively collapsing into a single, genetically uniform population.

Tasks

a) As an evolutionary biologist contributing to a regional biodiversity conservation seminar, write a technical paper addressing the following:

b) Explain how Species X and Species Y could have originally evolved from a single ancestral cichlid population within the same physical location, detailing the specific type of speciation and the ecological mechanisms that drove their initial divergence.

c) Identify and analyze the prezygotic isolating mechanisms that kept these two species genetically distinct prior to the increase in water turbidity.

d) Account for the genetic breakdown observed over the last ten years. Predict the long-term evolutionary fate of these cichlids if the water turbidity remains high, explicitly referencing the biological concepts of hybridization and fusion.

Item 16: Allopatric Speciation & Habitat Fragmentation

The Rwenzori Mountains region has seen significant infrastructure development over the past century. Historically, a single, continuous population of a flightless alpine beetle species (Montaneis rugosa) inhabited the continuous montane forest belt spanning an altitude of 2,500meters} to 3,000meters.

Seventy years ago, a major paved highway and wide asphalt transport corridor were constructed directly through the middle of this forest belt to link local mining hubs, completely dividing the forest into a Northern Sector and a Southern Sector. The highway clearing created a 100\text{-meter}-wide strip of hot, dry, asphalt terrain completely devoid of vegetation.

Recently, entomologists sampled beetles from both sectors. They noted the following variations:

Trait	Northern sector population	Southern sector population
Average body size	Small 1.2 cm	Large 2.8cm
Dietary preference	Lichens and mosses	Soft decaying hardwood bark

Mating behaviour	Pheromone based signaling	Vibrational leg stridulation/tapping on soil

When scientists placed mature males from the Northern Sector into a breeding enclosure with mature females from the Southern Sector, the beetles ignored each other completely. In the rare instances where mating was forced through artificial behavioral manipulation, the resulting eggs failed to hatch, showing early embryonic arrest.

Tasks

You have been hired by the National Environment Management Authority (NEMA) to write an evolutionary impact assessment report on the long-term effects of infrastructure corridors on native fauna. In your report:

a) Reconstruct the step-by-step evolutionary pathway that led the original uniform population of Montaneis rugosa to diverge into two distinct groups following the construction of the highway.

b) Classify and evaluate the specific reproductive barriers (both prezygotic and postzygotic) that now prevent successful reproduction between the Northern and Southern populations.

c) A student suggests that if we build a narrow "eco-bridge" (a vegetated overhead canopy walkway) across the highway, the two beetle groups will immediately merge back into a single species. Critically evaluate this claim based on the behavioral and physiological data provided in the table.

Item 17: Instantaneous Speciation via Polyploidy

In the wetlands surrounding Lake Kyoga, a native wild diploid water lily species, Nymphaea indigena (2n = 24), has grown stably for centuries. Two decades ago, an exotic, closely related diploid water lily species was accidentally introduced into the same wetland system.

Local botanists recently discovered a completely new variant of water lily growing aggressively in deeper waters where neither parent species typically thrives. This new variant possesses much larger leaves, thicker flower stalks, and highly vibrant petals.

Cytogenetic analysis revealed that the cells of this new variant contain a total chromosome number of 48 (4n). Laboratory trials show that when pollen from the new 4n variant is transferred to the stigma of the original wild 2n Nymphaea indigena, fertilization occurs, but the resulting seeds develop into plants that are completely sterile and incapable of producing viable pollen or ovules.

Tasks

Imagine you are a plant geneticist presenting your findings to the Botanical Society of Uganda. Prepare a detailed scientific presentation script that addresses the following:

a) Explain the cellular and genetic mechanism that allowed a new 4n species to emerge almost instantly in a single generation from the parental populations. State whether this represents autopolyploidy or allopolyploidy, justifying your answer.

b) Using genetic symbols or chromosome numbers, deduce why the offspring produced by crossing the new 4n variant with the original 2n parent species are completely sterile, explicitly detailing the mechanical issues that occur during Synapsis (Prophase I) of meiosis in the hybrid.

c) Discuss the ecological implications of this instantaneous speciation event. Why might the new 4n polyploid variant possess phenotypic advantages (like larger leaves and thicker stalks) that allow it to colonize deeper water niches compared to its diploid parents?

Item 18

A livestock breeder in Kiruhura district operates a commercial farm specializing in indigenous **Ankole cattle**. He notices that a specific structural defect—extremely short, weak limbs (locally termed the "dwarf trait")—occasionally manifests in some of his calves. This trait prevents the cattle from grazing efficiently on hilly terrain.

The breeder bought a premium, highly muscular bull with normal long limbs from an external ranch to serve as his primary sire. Over two years, this bull mated with 40 phenotypically normal cows from the local herd. The resulting F1 generation consisted of 120 calves, all of which had perfectly normal long limbs.

However, when the breeder subsequently mated the same premium sire with five specific normal-limbed cows that had previously given birth to dwarf calves with a different bull, two of the resulting offspring exhibited the dwarf trait. The breeder is confused about how two structurally normal parents can produce a deformed calf.

Tasks

a) As an animal geneticist consulting for the Kiruhura Dairy and Livestock Association, draft an advisory technical report addressing the following:

b) Deduce the mode of inheritance of the dwarf trait in these Ankole cattle, justifying your conclusion using evidence from both sets of mating described in the scenario.

c) Using appropriate genetic symbols, construct genetic diagrams (showing parental genotypes, gametes, and a Punnett square) for the second cross to demonstrate how the dwarf phenotype re-emerged.

d) The breeder wants to sell the premium sire bull but needs to guarantee to buyers that it is a "pure-breeding" line for long limbs. Evaluate the genetic cross the breeder unwittingly performed with the five specific cows, and explain how a systematic Test Cross can confirm the exact genotype of any structurally normal animal on his farm.

Item 19

The National Agricultural Research Organisation (NARO) in Kawanda is breeding improved varieties of the common bean (Phaseolus vulgaris) to enhance food security. Researchers are focusing on two distinct traits:

Seed Coat Texture: Controlled by a gene where the allele for smooth texture (S) is completely dominant over the allele for wrinkled texture (s).

Pod Color: Controlled by an independent gene where the allele for yellow pods (Y) is completely dominant over the allele for green pods (y).

A research scientist crosses a pure-breeding plant that produces smooth seeds and yellow pods with another pure-breeding plant that produces wrinkled seeds and green pods. The resulting F1 generation is self-pollinated to produce an F2 generation.

The harvesting team collects a total of 1,600 bean seeds from the F2 plants. The farm manager needs to sort and package these beans for distribution to farmers. The smooth-seeded, green-podded variety is highly demanded by export markets, while the wrinkled-seeded, green-podded variety is rejected by consumers.

Tasks

Act as the Lead Biostatistician at the research station. Produce a crop production analysis brief containing the following sections:

a) State Mendel's Law of Independent Assortment and justify why this law applies to the inheritance of seed coat texture and pod color in this specific NARO breeding program.

b) Construct a dihybrid Punnett square representing the F2 generation. Based on this, predict the exact expected numerical count of: Beans that are highly demanded by the export market (smooth seeds, green pods). Beans that will likely be rejected by consumers (wrinkled seeds, green pods).

c) During sorting, the actual count of smooth-seeded, green-podded beans deviates slightly from your mathematical prediction. Explain the biological and statistical reasons why observed phenotypic ratios in living populations rarely match theoretical Mendelian ratios perfectly, and state how sample size influences this variance.

Item 20

A family in Hoima city visited a genetic counseling clinic at the regional referral hospital. The parents, John and Mary, are healthy and have normal vision. They have four children: two daughters (Grace and Joan) and two sons (Peter and David).

Peter suffers from an inherited, severe structural eye disorder that causes progressive night blindness, while David has perfectly normal vision. Both Grace and Joan have normal vision. Peter recently married a woman named Alice who has a family history of the same eye disorder, though she does not display symptoms herself. Peter and Alice have just had their first child, a boy named Alex, who has been diagnosed with the structural eye disorder.

The family is distressed, and some relatives are blaming the condition on cultural superstitions or environmental toxins from nearby oil refinery construction.

Tasks

As the Lead Genetic Counsellor at the hospital, write a clinical assessment and counseling booklet for this family. Your booklet must:

a) Construct a standardized Genetic Pedigree Chart spanning the three generations described in the scenario (John/Mary, Peter/Alice and siblings, and young Alex). Use standard symbols (squares for males, circles for females, and shaded shapes for affected individuals).

b) Deduce whether the gene causing this structural eye disorder is dominant or recessive, and whether it is autosomal or sex-linked. Provide clear, step-by-step diagnostic reasoning using specific individuals from the pedigree to debunk the environmental toxin theory.

c) Calculate the exact probability that Grace (Peter's normal-vision sister) is a carrier of the defective allele. Advise the family on the mathematical likelihood of John and Mary having another affected child if they choose to conceive again.

Item 22: Synaptic Transmission, Neurotoxins, and Effector Function

A rural health center in Bugiri district receives a patient who was rushed from a commercial rice farm. The patient is experiencing severe muscle tremors, profuse sweating, constricted pupils, and difficulty breathing. A fellow worker reports that the patient was spraying a high-concentration organophosphate pesticide without wearing protective face masks or gloves.

The medical officer explains to the family that the pesticide chemically binds to and permanently inhibits the enzyme acetylcholinesterase within the patient's neuromuscular junctions and

cholinergic synapses. The family is confused about how a chemical meant to kill crop pests can paralyze a human being's breathing muscles.

Tasks

Act as the Senior Medical Officer compiling a clinical toxicology briefing for the district health team. In your briefing:

a) Draw an annotated schematic diagram of a typical cholinergic synapse to illustrate the step-by-step process of normal neurotransmitter release, diffusion, and subsequent inactivation.

b) Analyze the precise electrochemical and physiological consequences that occur at the postsynaptic membrane when acetylcholinesterase is inhibited by the organophosphate pesticide. Explain how this leads to the patient's continuous muscle tremors.

c) Formulate a biological justification for the use of an emergency drug treatment that blocks postsynaptic acetylcholine receptors (such as atropine) as an effective antidote to stabilize the patient's respiratory effectors.

Item 23

A group of tourists on a walking safari in Kidepo Valley National Park unexpectedly encounters a lone cape buffalo emerging from dense thickets just ten meters away. Instantly, the tourists experience a massive surge of adrenaline. Within fractions of a second, their heart rates skyrocket, their pupils dilate, and their skeletal muscle blood vessels dilate, allowing them to sprint rapidly toward a nearby safety vehicle.

Two hours after safely reaching the safari lodge, the tourists note that while their initial panicked running response was triggered instantly, their heart rates and breathing rates remained slightly elevated for a long time, and they felt a lingering state of alertness for hours, despite knowing the danger had completely passed.

Tasks

a) Produce a comparative physiological essay for a wildlife conservation and human-physiology journal explaining the tourists' body responses. In your essay:

b) Contrast the initial, immediate "fight-or-flight" activation triggered by the Sympathetic Nervous System with the subsequent, prolonged effects caused by the release of Adrenaline from the adrenal medulla.

c) Explain why the nervous system response was capable of triggering an instantaneous behavioral reaction (within milliseconds), whereas the hormonal response took longer to

peak but sustained its physiological effects for hours. Reference their transmission mediums and cellular mechanisms.

d) Explain the evolutionary and survival advantages of having two interconnected, overlapping coordination systems (neural and endocrine) react to a single environmental threat rather than relying on just one system.

During a public health immunization campaign against a re-emerging viral pathogen in East Africa, the Ministry of Health evaluated two different vaccine designs:

Vaccine A: A traditional inactivated virus vaccine.

Vaccine B: A modern mRNA-based nanoparticle vaccine.

A clinical trial monitored the blood serum antibody concentrations (titer levels) of two volunteer groups over a 60-day period. Both groups received an initial injection on Day 0 and a booster injection on Day 28. The quantitative results are presented in the data matrix below:

Time line	Vaccine A antibody titer/ iu/ml	Main immune cells detected in group A	Vaccine B antibody titer/iu/ml	Main active cells detected in group B
Day 0	0	Naïve B lymphocytes	0	Naïve B lymphocytes
Day 7	12	Plasma cells	45	Helper T cells
Day 14	35	Plasma cells, memory B cells	180	Plasma cells ,cytotoxic cells
Day 28	8	Memory B cells	90	Memory B and T cells
Day 35	150	Plasma cells/rapid division	1200	Plasma cells, memory T cells
Day 60	95	Long lived memory cells	980	Long lived memory B and T Cells

Tasks

As a Senior Immunologist at the Uganda Virus Research Institute (UVRI), prepare an advisory evaluation report for the National Medical Stores regarding procurement selection. Your report must:

a) Construct a single, clearly labeled line graph comparing the antibody titer profiles over time (Days 0 to 60) for both Vaccine A and Vaccine B.

b) Contrast the Primary Immune Response (Days 0–28) with the Secondary Immune Response (Days 28–60) for Vaccine A. Explain the cellular mechanisms responsible for the differences in speed and magnitude of antibody production.

c) Analyze the cellular data from Day 14. Explain why Vaccine B triggered a significantly higher antibody titer and activated Cytotoxic T-lymphocytes, whereas Vaccine A did not. Conclude which vaccine provides superior herd immunity against an intracellular viral pathogen.

ALUTA CONTINUA